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First Fossil Record of the Family Phormosomatidae (Echinothurioida: Echinoidea) from the Early Miocene Morozaki Group, Central Japan

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ABSTRACT—A fossil echinothurioid echinoid is described from the Early Miocene Morozaki Group in the Chita Peninsula of Aichi Prefecture, central Japan. Based on geological observations, the fossil species is supposed to be the inhabitant of the bathyal zone. The diagnosis of the species is as follows: A small body size for an echinothurioid, large and deep areoles in the oral side, slender teeth with a sharp point, and a large peristome area. From the supposed habitat and the diagnosis, this species is considered to be identical with or a direct ancestor of *Phormosoma bursarium,* a common extant species in the bathyal zone of the Indo-Pacific region including the southern coasts of the Japanese main islands. This is not only the first fossil record in the world of the family Phormosomatidae, but also the third fossil species for the order Echinothurioida.

INTRODUCTION

Fossil echinothurioid echinoids have scarcely been found because the echinothurioids have flexible tests with rich connective tissue and poorly calcified ossicles [19]. Extant echinothurioids are divided into two families, Echinothuriidae and Phormosomatidae [7, 18, 19]. As the firm records, only two fossile species of echinothurioids have been reported [19]. One species is *Echinothuria floris* from the Upper Cretaceous of the British Chalk [20], and another is *Araeosoma thetidis* from the Pliocene of New Zealand [4, 19]. No fossil phormosomatid has been reported so far [19].

The sea along the Pacific coast of the Japanese main island is so extensively exploited that some groups of organisms known elsewhere only from the deep sea seems to occur there in relatively shallower waters. Echinothurioids are one of such groups, and a considerable number of species of the order can be found. The extant species of echinothurioids found on the bottom of or shallower than the upper bathyal zone in the Japanese coast include 5 species of the Echinothuriidae: *Asthenosoma ijimai* from the infralittoral zone, *Araeosoma owstoni* and *Hapalosoma gemmiferum* from the circalittoral (lower sublittoral covering the edge of continental shelf) zone, and *Calveriosoma gracile* and *Hygrosoma hoplacantha* from the upper to middle bathyal zone [1, 2, 8, 10–13, 16, 21], and one species of the Phormosomatidae, that is *Phormosoma bursarium* from the upper bathyal zone [8, 10–13, 16]. However, fossil specimens of echinothurioids have never been reported from Japan.

Miocene deposits known as the Morozaki Group are distributed widely in the southern area of Aichi Prefecture. The Group is characterized by extremely rich marine fossil fauna consisting of bathyal and mesopelagic assemblage [14]. Recently, we obtained a large amount of deep-sea fossils comprising fishes, echinoderms, crustaceans and molluscs, from sandstone and mudstone beds in the Morozaki Group. Among those, some specimens of the Phormosomatidae were found.

In the present paper, a fossil phormosomatid species is described on the basis of seven specimens, and its affinity with *P. bursarium* is discussed.

MATERIALS

The Morozaki Group is distributed in Saku-shima and Himaka-shima Islands in Mikawa Bay, and the southern edge of the Chita Peninsula in Aichi Prefecture situated in central Japan (Fig. 1). The group is subdivided into four formations which are the Himaka, Toyohama, Yamami, and Utsumi Formations in ascending order [14]. The fossil phormosomatid specimens examined were collected with many other echinoderm species (ca. 17 species) from the Toyohama and Yamami Formations (Fig. 1: Locs. 1–3) and were found in the tuffaceous sandstone beds deposited in the bathyal zone between around 500 m to 1,000 m depth or more [5].

The geologic age of the Toyohama and Yamami Formations was estimated to be Middle Miocene, 15.5 Ma to 16.5 Ma [14, 15]. But recent biostratigraphic studies based on planktonic foraminifers [3] and paleomagnetic study [6] showed that the formations are Early Miocene in age. These formations contain various kinds of fossil species including phormosomatid echinoids. They are composed of benthic, nektonic and planktonic organisms such as fishes, crustaceans, molluscs and protozoans having inhabited various depth zones from littoral to bathyal [17]. Echinoids were abundant and accounted for more than a half of the echinoderm specimens collected from the formations.

More than ten specimens of fossil phormosomatids were collected. Six of them (MFM 38057–38060, MI 01, SA 01) are almost intact, and others are fragmental. The fossil specimens examined in this study are deposited in the Mizunami Fossil Museum (MFM

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38057–38060), the Misaki Marine Biological Station (MMBS A1), and in the private collections of Y. Mizuno (MI 01) and F. Sakakura (SA 01).

MFM 38057, 38060, and MI 01 were found in a tuffaceous sandstone bed of the lower part of the Yamami Formation (Fig. 1: Loc. 2), together with crinoids, ophiuroids, crustaceans and molluscs.

MFM 38057 was collected from a sandstone bed of the uppermost part of the Toyohama Formation (Fig. 1: Loc. 1), together with asteroids and ophiuroids.

MFM 38058 and SA 01 was collected from a tuffaceous mudstone bed of the middle part of the Yamami Formation (Fig. 1: Loc. 3), together with asteroids, ophiuroids, crustaceans, molluscs and fishes.

The living specimens of *Phormosoma bursarium* (MMBS P1–P7) for comparison were collected from Suruga Bay at 550 m in depth.

SYSTEMATIC DESCRIPTION

Order Echinothurioida Claus, 1880
Family Phormosomatidae Mortensen, 1934
Subfamily Phormosomatinae Mortensen, 1934
Genus *Phormosoma* Thomson, 1872
Phormosoma sp. cf. *P. bursarium* A. Agassiz, 1881

Diagnosis: 1, a small body size for an echinothurioid; 2, large and deep areoles in the oral side; 3, slender teeth with a sharp point; 4, a large peristome area.

Description: This description is based on six intact (MFM 38057–38060, MI 01, SA 01) and one fragmental (MMBS A1) specimens. The test is circular and rather small in size for an echinothurioid with the diameters ranging from 48 mm to 118 mm (Table 1). The size is comparable to that of *Phormosoma bursarium,* an extant species, but somewhat larger than the other extant species, *P. placenta, P. rigidum,* and *P. verticillatum,* none of which reaches a larger size than 90 mm in diameter [8]. Specimens are squashed along the oral-aboral axis. In most specimens, the oral side is well preserved (Fig. 2), but the aboral side is damaged heavily, or lost. The oral side of the test looks like a honey-comb (Figs. 2, 3), because the areoles of the primary tubercles in the oral side are very large and deep. The five pieces of teeth in the lantern are slender with sharp points (Figs. 2, 4). The areoles in the aboral side, in contrast to the oral side, are small and not so deep (Fig. 4). The peristome area is large (Figs. 2, 4), although not so large as in *P. bursarium* (Table 1). Interambulacra on the oral side are almost 2.5 times as broad as ambulacra, somewhat larger (ca. twice) than in *P. bursarium.* Plates are large, not numerous. An ambulacral plate is composed of a large primary plate and two small demiplates which are situated at the side of the lower edge of the primary plate (Fig. 3). Three pairs of pores are found on these plates. A pair of pores is situated in the margin of the primary plate. Another pair of pores is on each demiplate.

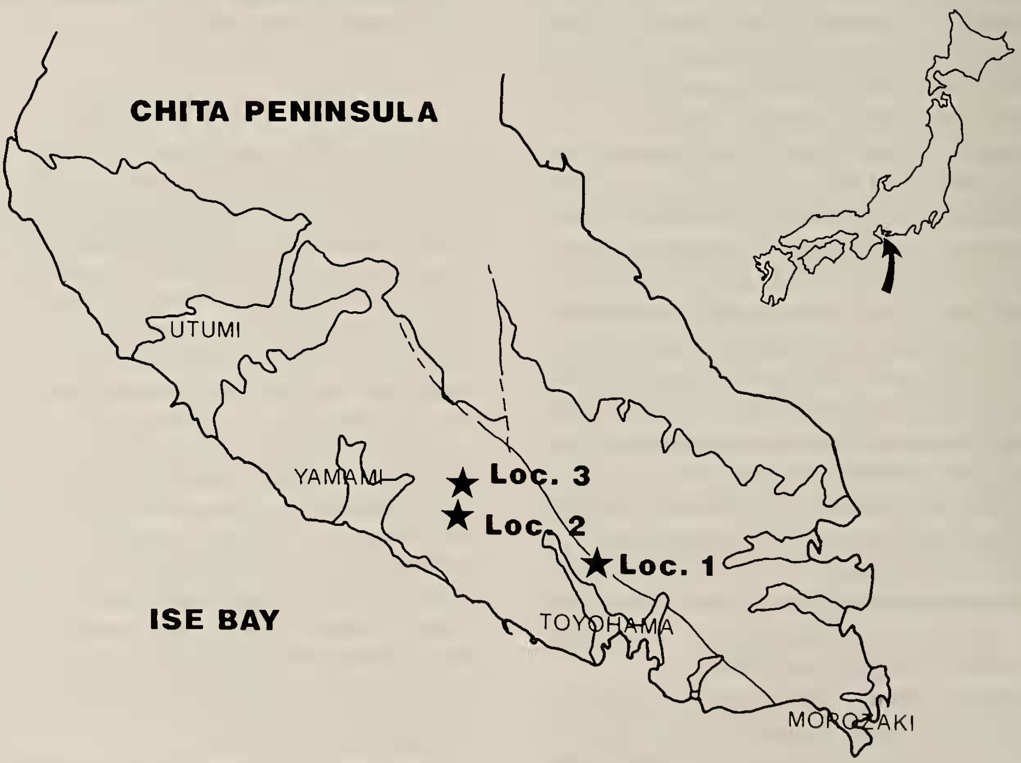


Fig. 1. Map showing the Toyohama and Yamami Formations and Localities 1–3 (Locs. 1–3) in the Morozaki Group in the Chita Peninsula, from where the Miocene phormosomatid specimens were collected. Curved arrow shows the location of the Chita Peninsula in the Japanese main islands.

Table 1. Size distribution of tests and peristomes in fossil *Phormosoma* sp. and living *Phormosoma bursarium*

Phormosoma sp.				*P. bursarium*			
Cat. No.	test diameter (A) (mm)	peristome diameter (B) (mm)	B/A	Cat. No.	test diameter (A') (mm)	peristome diameter (B') (mm)	B'/A'
MFM 38060	48	15	0.31	MMBS P1	78	30	0.38
MFM 38058	63	17	0.27	MMBS P2	79	24	0.30
MI 01	74	23	0.31	MMBS P3	79	28	0.35
MFM 38057	82	21	0.26	MMBS P4	89	33	0.37
MFM 38059	100	25	0.25	MMBS P5	92	28	0.30
SA 01	118	31	0.26	MMBS P6	94	36	0.38
				MMBS P7	109	36	0.33
Mean			0.277				0.344
±S.D.			±0.027				±0.035

There are five to six pairs of primary plates in each ambulacrum on the oral surface, and an ambulacral primary tubercle is on each primary plate. The size of the primary tubercles is almost equal except in the ones situated along the peristome which are somewhat smaller than others.

There are four to six interambulacral plates in each column on the oral surface. The number of primary tubercles on an interambulacral plate decreases adapically from 3 (for the outermost 1–2 plates), 2 (for the inner 2 plates) to 1 (for the 1–2 plates adjacent to the peristome). Secondary and miliary tubercles are not preserved. The spines preserved on the marginal fringe of the test of MFM 38058 are short and slender (Fig. 5). The apical system is not preserved well.

Remarks: The specimens from the Morozaki Group have large and deep areoles in the oral side, slender teeth with a sharp point, a large peristome area, and a comparatively small body size. These characteristics clearly indicate that they belong to the genus *Phormosoma* Thomson, 1872. Four extant species belonging to the genus *Phormosoma* have so far been reported [8]. Their distributional ranges are as follows:

P. placenta Thomson, 1872: Northern Atlantic from Iceland and the Davis Strait down to the Azores and the Gulf of Guinea, and to the West Indies, 215–2500 m depths.

P. verticillatum Mortensen, 1904: Indian Ocean, from the Bay of Bengal to the Arabian Sea, 1165–1925 m depths.

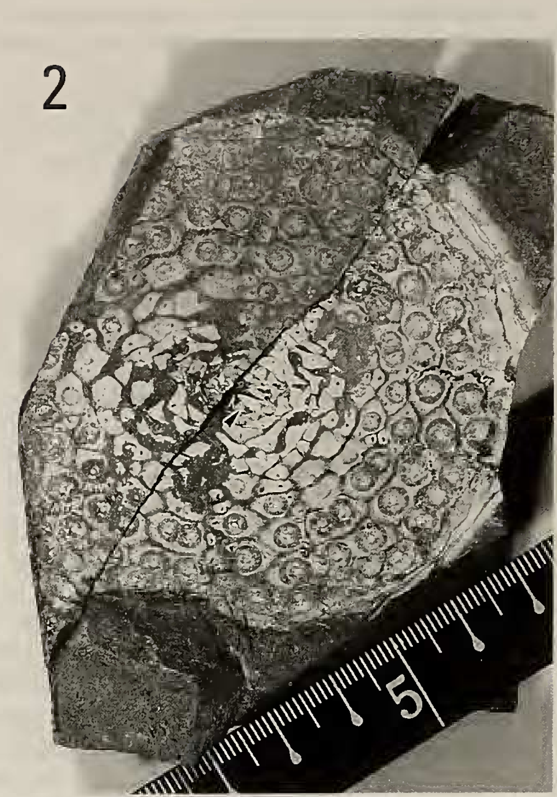
P. rigidum A. Agassiz, 1881: Off New Zealand, 1260 m depth.

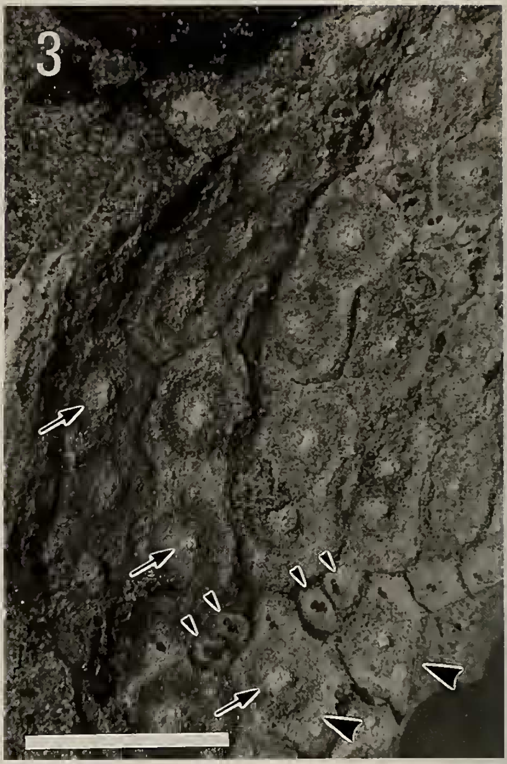
P. bursarium A. Agassiz, 1881: Indo-Pacific, from the Natal Coast and the Arabian Sea to Australia, New Caledonia, Japan, and the Hawaiian Islands, overall depth range in records 170–2340 m, and dominate between depths of 500–1700 m on the continental slope of the Pacific coast of Japan.

The Morozaki specimens have affinity with *P. bursarium* in some morphological characters such as the test size, or the arrangement of ambulacral plates and pore pairs on the plates, although some differences are also found between them in the peristome area and in the relative width of the ambulacra and interambulacra.

Their habitats seem also to be similar, and a great number of living specimens of *P. bursarium* have been trawled and sometimes gregarious paches of them were photographed on the silty mud bottoms of the bathyal zone along the southeastern coast of Japanese main islands including the area off the Chita Peninsula [12]. The depth range of *Calveriosoma gracile* and *Hygrosoma hoplacantha* overlaps with that of *P. bursarium* in the above locations. However, the usual habitats of them are segregated. The former two species prefer sandy mud bottom on the topographic highs swept by strong bottom currents expecting the occasional drifting sea algae as facultative vegetarians [9, 12], whereas the latter species predominates on the silty mud floor where the regime of bottom water movement is relatively calm. If the habitat of the fossil species is the same as that of the extant species, the taphonomy of the soft-shelled sea urchin in the taffaceous sandstone in a formation of Morozaki Group suggests instantaneous burial beneath turbidity currents. The present *Phormosoma* specimens were collected together with four other echinoid species, 13 species of other echinoderms and with some fishes, crustaceans and molluscs from tuffaceous sandstone beds deposited in the bathyal zone. The four echinoid species are *Temnopleurus* sp. (upper bathyal member), *Brissopsis* sp. (upper to middle bathyal member), a diadematid and a scutellid (littoral members). Their habitats today range from the littoral to bathyal zones, suggesting that some of the fossils have been brought from shallower bottoms into the bathyal zone by turbidity flows and/or episodic disasters involving the littoral, midwater and upper continental slope realms.

The fossil specimens found in the Morozaki Group can be identical with or a direct ancestor of *P. bursarium*, although the information obtained from the present fossil specimens is still insufficient to identify the species exactly. This is the first fossil record in the world of the family Phormosomatidae, and is also the third unequivocal fossil species for the order Echinothurioida [19].





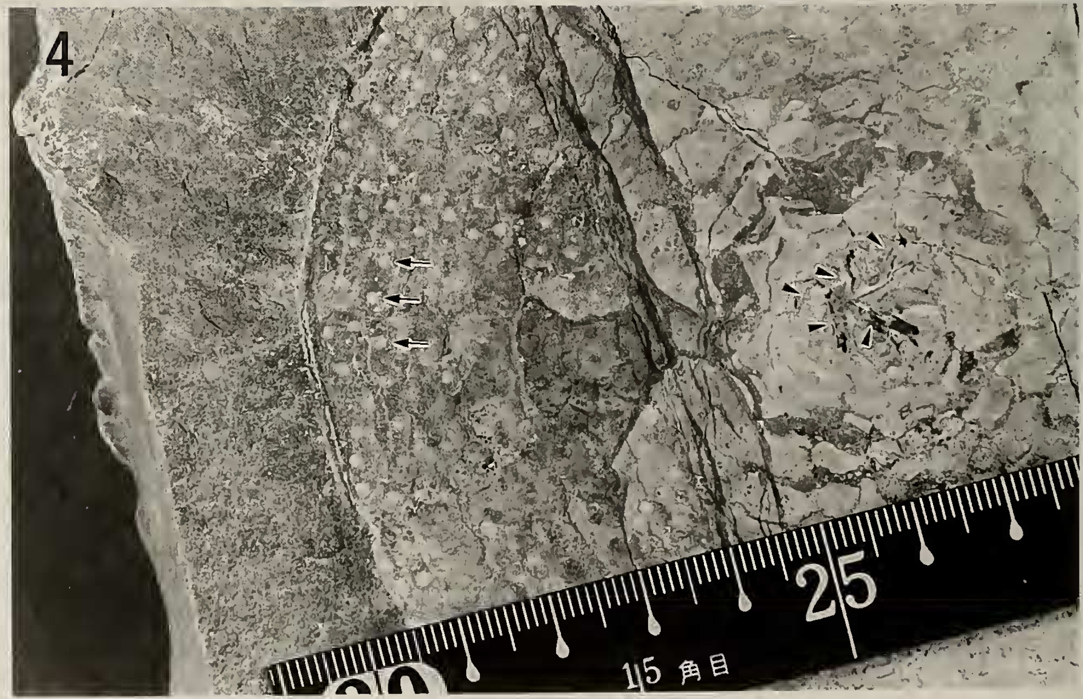


FIG. 2. Oral view of *Phormosoma* sp. (MFM 38057) showing a honey-comb-like structure with large and deep areoles and a large peristome area. A sharp and slender tooth (arrow-head) in the mouth is also seen. The smallest graduation of the measure corresponds to 1 mm.

FIG. 3. Ambulacral and interambulacral plates on the oral-side of *Phormosoma* sp. (MMBS A1) viewed under a higher magnification than in Fig. 2. The areoles (arrows) of the primary tubercles are very large and deep. Large and small arrow-heads show the primary ambulacral plates and the demiplates, respectively. Bar represents 1 cm.

FIG. 4. Oral view of *Phormosoma* sp. (SA 01). Arrow-heads indicate the five slender teeth in the mouth. Part of the test has been removed and the coelom-side of the aboral test is seen in the left-side of the field. The areoles (arrows) on the aboral test are small. The smallest graduation of the measure corresponds to 1 mm.

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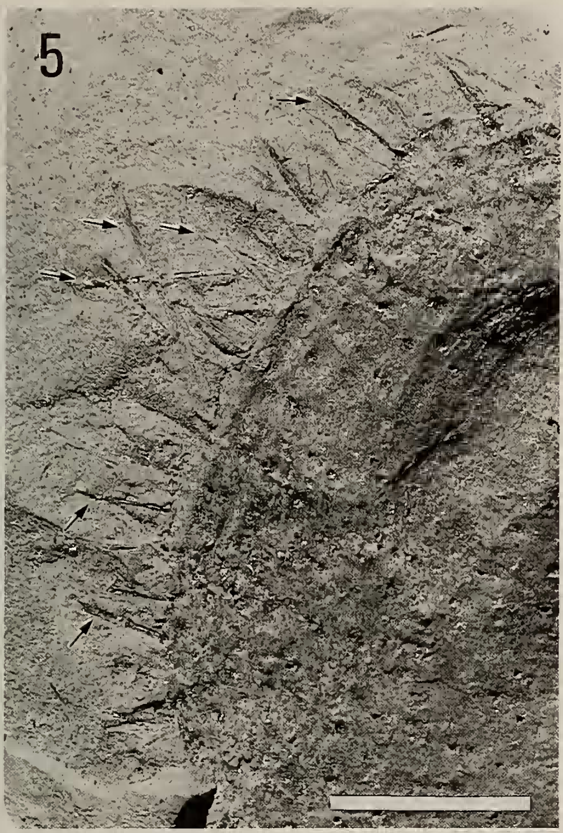

Fig. 5. The short and slender spines (arrows) on the marginal fringe of the test of *Phormosoma* sp. (MFM 38058). Bar represents 1 cm.

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